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National Ice Center

Science Plan

Version 6.0   17th December 1997

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Approved

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date _____

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Abstract

This document represents a plan for the National Ice Center science program. The plan lists the aims of the program, justifies those objectives in terms of National Ice Center and sponsor program objectives and proposes a set of activities which are shown to be consistent with the medium term plans of the National Ice Center.

Science Plan

Table of Contents

1. Introduction

This report provides a plan for the activities of the Science program, newly formed at the National Ice Center (NIC) and sponsored by the National Oceanic Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) and the Navy's Office of Naval Research (ONR). The plan meets program requirements of both the sponsors and the National Ice Center and will form the framework for the activities of the science unit at the NIC for the period 1997-1999. The plan focuses strongly on operational product requirements, as it is targeted at the scientific community to enhance awareness of the operational requirements. The activities of the Science Unit are expected to have scientific as well as benefits.

Section 2 of the report introduces the National Ice Center. Section 3 outlines the high level requirements for the science program, as drawn up by NIC in consultation with the sponsors ONR, NOAA and NASA. Section 4 reviews medium term objectives for product support at the NIC, which will form the context for the science program. Sections 5 and 6 outline the activities in detail and sections 7 and 8 provide a schedule and summary of recommendations, respectively. Appendices include a glossary of acronyms, a summary of the North Open Water experiment, and a review of algorithm and product requirements at the NIC.

2. The US National Ice Center

The mandate of the NIC is to provide global sea ice analyses, forecasts, outlooks and ship routing recommendations within the marginal ice zone of all Arctic and Antarctic seas, with support from the US Navy, NOAA and the United States Coast Guard (USCG). The organizational structure is shown in Figure 1.
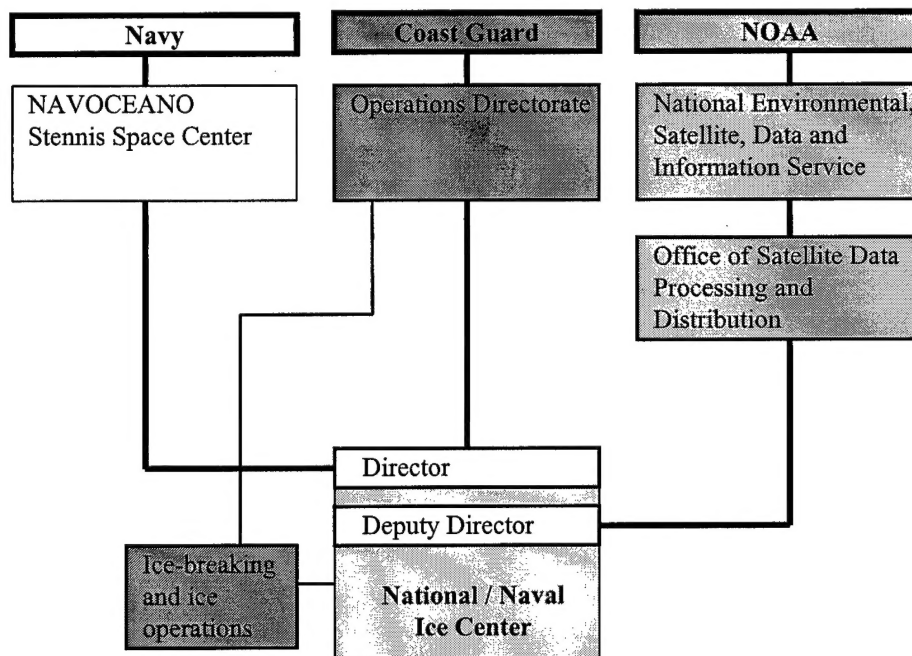

Figure 1. Organizational context of the NIC.

The NIC currently acquires data from a wide variety of sources, including aerial reconnaissance ice observations, opportunistic ship reports, foreign ice charts, passive microwave satellite data (SSM/I), visible and infra-red satellite data (NOAA AVHRR and DMSP OLS) and active microwave satellite data (ERS-2 and RADARSAT). These data sets are acquired in near real time and from these, together with an operational ice-ocean model (PIPS 2.0), the NIC generates digital ice charts and forecasts. The ice charts are used to update digital climatologies, which are based on charts stretching back to 1972. The ice charts and forecasts are currently provided on a weekly basis for all sea-ice prone regions of the World, with each ice chart covering a relatively well-defined region (such as the Bering Sea).

Ice charts are generated using a combination of analyst skill and data manipulation tools within a Geographic Information System and image processing environment. The received data are obtained in both geocoded and non-geocoded forms (depending on sensor and ground station), and in different formats. Preliminary batch processing facilitates the organization of these diverse data sets at NIC into region-based directories. Automated algorithm processing is currently limited to the generation of SSM/I - derived ice concentrations (obtained from outside the NIC at the Fleet Numerical Modeling and Oceanography Center, FNMOC and NCEP). The image analysis environment, Naval Satellite Image Processing System (NSIPS), supports a wide range of low level image manipulation tasks, including (for example), image zooming, co-registration, constrast stretching and mosaicking. NSIPS has also served as a host for experimental algorithms in the past. Analysts currently use NSIPS to display and manipulate data, starting with the highest resolution observations available, and ending with SSM/I - derived ice concentrations for areas which have no higher resolution data available. The vector-based ice charts are saved as gif files (Figure 2).

The completed ice charts, as well as Arc-Info vector and attribute files, are disseminated via the internet (www.natice.noaa.gov) or autopoll facsimile.
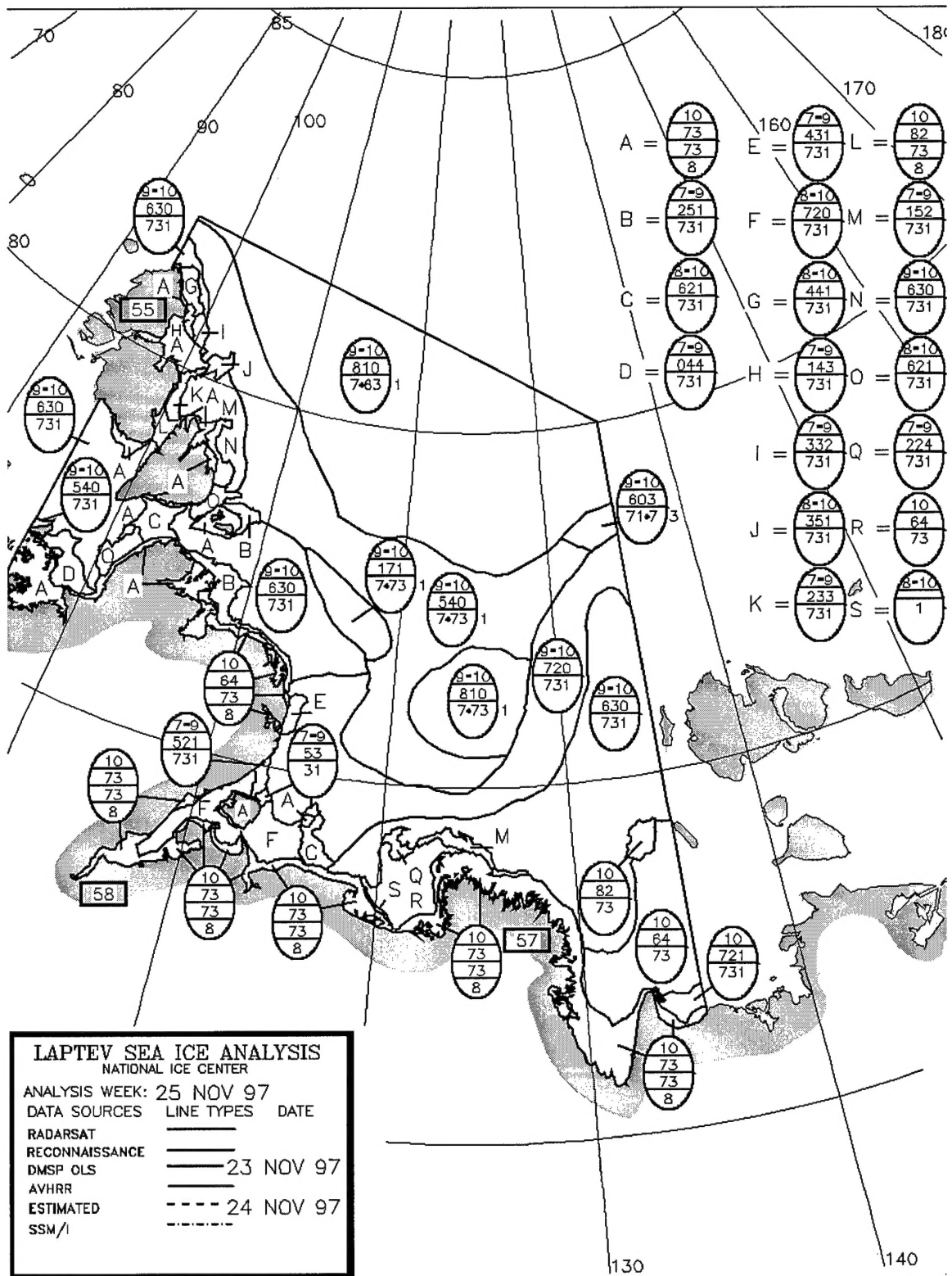
Figure 2. Example NIC ice chart product: Laptev Sea.

3. NIC Science Program Background and Objectives

In order to carry out its mandate, the NIC acquires a range of data sets appropriate for Arctic and Antarctic observations and requires that these are processed in a timely and efficient manner. The NIC is therefore in constant search for technology which can assist in this aim. A key source of technology lies within the scientific community, where projects undertaken with scientific objectives often have operational application or by-products. At the same time, the NIC data and products are a potential resource for the scientific community and can be used to evaluate algorithms and products. It therefore behooves both the NIC and the academic community to establish strong links via sponsors (ONR, NASA and NOAA). This process has been set in motion through the NIC science program.

The specific aims of the science program are as follows:

1. To **plan, coordinate and carry out product evaluation activities** which will support feedback to scientists and NIC operations. The NIC science program will act as a focal point for product evaluation and can provide liaison with the US Coast Guard and Navy for campaign support involving aerial reconnaissance, trained ice observers and loan of instrumentation.

2. To provide a **voice for operational requirements** within the scientific community. To seek to influence the direction of scientific endeavor to support operational requirements, through participation in proposals and studies, thus increasing the range of applications and benefits to the taxpayer of scientific projects. The aim here is to emphasize not only the range, accuracy and precision of products, but also computational efficiency, with the eventual transitioning of successful algorithms to NIC operations. Such transitioning will be supported by NIC resources where appropriate.

3. To be a **source of scientific expertise** for the NIC. To maintain an effective awareness and critical judgment regarding the quality and scope of scientific work which is available to the NIC for future operational use, allowing the **recommendation, planning and coordination of projects which support improved operations**. This will be based on the current priorities of operational issues at the NIC.

4. To **encourage the use of NIC products and resources by the scientific community**. This should include transition of products to data archiving facilities as appropriate. The NIC has access to data sets which are of wide value, including satellite data and digital ice climatology data. The NIC science program can also encourage, and assist with, the migration of appropriate products and data sets to Data Active Archive Centers, such as the National Snow and Ice Data Center.

5. To act as a **focus for inter-agency cooperation**, assisting with recommendations on operational relevance of proposed projects.

4. The Evolution of NIC Products and Services

The content of the NIC science plan needs to relate closely to the operational objectives of the National Ice Center, while at the same time addressing the interests of the sponsoring agencies. Given the duration of sponsorship of the program, the objectives of the NIC over the next 5 years are the most appropriate time scale to consider. In this section, a vision for how NIC products and services will develop over the next five years is summarized, based on the results of an internal workshop held at NIC in October, 1997. It should be noted that this vision is preliminary, as it anticipates the results of a customer survey being undertaken by NIC.

4.1 Anticipated Products

For the purposes of this Science Plan, it is assumed that the weekly, regional ice chart products generated globally by NIC will be replaced by a daily, global product and daily, regional product. This will match more closely the needs of customers for strategic ("large picture") products and tactical ("frequent, detailed, local picture") products. To balance the increased temporal resolution, it is unlikely that the tactical product will continue to be available for all sea-ice prone regions. Thus, the NIC will more closely match other national ice centers in focusing on regions of national interest. However, the strategic product will continue to be global in coverage, thus meeting the mission of the NIC. These new product requirements are shown in Table 1.

Region	Area	Strategic product		Tactical product			
		Daily, year-round, low res'n product	Seasonal outlook	Start date	End date	Daily, seasonal, high res'n product	72-120 hour forecast product
Antarctica	Ross	Yes	Yes	1 Oct.	28 Feb.	Yes	Yes
	Rest	Yes	No	1 Jan.	31 Dec.	On demand	On demand
West Arctic	Beaufort	Yes	Yes	1 Apr.	30 Nov.	Yes	Yes
	Chukchi	Yes	Yes	1 Apr.	31 Dec.	Yes	Yes
	Bering	Yes	Yes	1 Nov.	31 Jul.	Yes	Yes
	Okhotsk	Yes	Yes	1 Dec.	30 Jun.	Yes	Yes
	Japan	Yes	Yes	1 Dec.	30 Jun.	Yes	Yes
	Canadian	Yes	Yes				
	E. Siberian	Yes	Yes				
	Laptev	Yes	Yes				
	Yellow	Yes	Yes	1 Dec.	30 Apr.	Yes	Yes
East Arctic	High Arctic	Yes	Yes				
	Canadian	Yes	Yes				
	Baffin	Yes	Yes				
	St. Lawrence	Yes	Yes				
	E. Greenland	Yes	Yes	1 Jan.	31 Dec.	Yes	Yes
	Barents	Yes	Yes	1 Jan.	30 Apr.	Yes	Yes
	Kara	Yes	Yes	1 May	30 Nov.	Yes	Yes
	Baltic	Yes	Yes				
Other	Great Lakes	No	Yes	1 Nov.	1 May	Yes	Yes
	Chesapeake/ Delaware	No	Yes	1 Jan.	31 Mar.	Yes	No

Table 1. Products anticipated by 2002. Shaded cells indicate that no product will be available, except upon specific request.

4.2 Anticipated Data

The sources of satellite data expected to be available to generate ice products sometime during 1997-2002 are listed in Table 2. In addition, in-situ reports and foreign analyses will continue to be used and digital climatology data will also become increasingly important as a means of providing confidence in the products.

Satellite	Sensor	Frequency band	Spatial Res'n meters	Country	Launch date	Anticipated operational status
TIROS	AVHRR	VIS/IR	1100 - 4000	USA	past	operational
DMSP	SSM/I SSMIS	MW MW	12,500 - 25,000 12,500 - 25,000?	USA	past, 1999 2001	operational
DMSP	OLS	VIS/IR	550 - 2700	USA	past	operational
NPOESS	follow-on to DMSP and NOAA satellites			USA	2008	operational
GOES-N	VAS	VIS/IR	4000	USA	past?	operational[1]
RADARSAT	SAR	MW	10 - 150	CAN	past, 2000	operational
EOS	MODIS	VIS/IR	250 - 1000	USA	2000	operational[2]
ENVISAT	ASAR	MW	30 - 1000	ESA	1999	back-up
EOS	AMSR	MW	11,600	USA	2000	back-up
QuikSCAT	SCAT	MW	25,000	USA	1998	experimental
ENVISAT	AATSR	VIS/IR	1000	ESA	1999	experimental
ENVISAT	MERIS	VIS/IR	300 - 1200	ESA	1999	experimental

[1] Great Lakes only; [2] subject to good quality ice algorithm

Table 2. Anticipated sources of satellite data, 1997-2002. Operational status is defined as follows. *Operational* means that the data will be used as a primary source of data for operations with processing systems and communications established for accessing and analyzing the data. *Back-up* means that the data are candidates as a source of data should a primary data stream become unavailable. In addition, if these data sources are demonstrated to be available on an operational basis, it is possible that they could augment the existing operational sensors. *Experimental* means that the data are unlikely to be used operationally during the next 5 years, but that there is interest in ascertaining their potential for ice monitoring.

4.3 System Design

In order to achieve the anticipated product requirements with the available sensors and NIC resources, the following (relatively generic) system is envisaged.
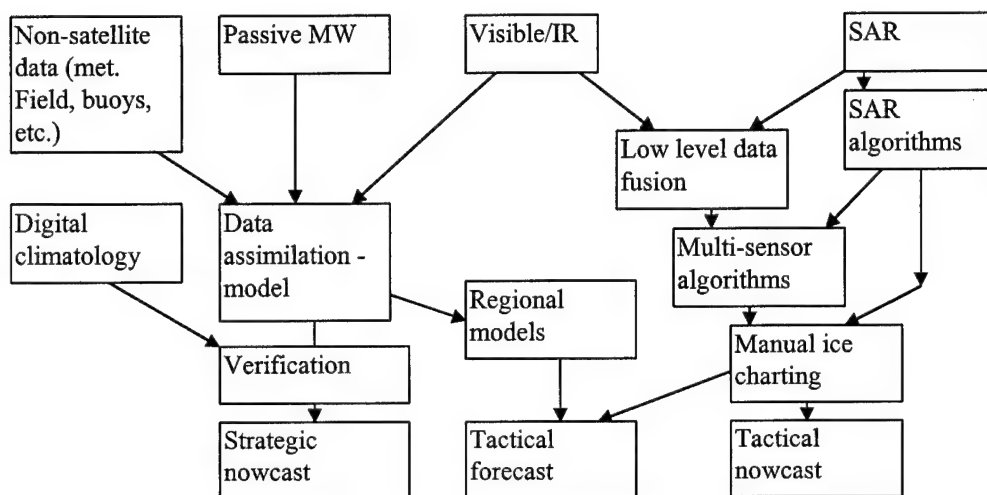
Figure 3. Generic data processing system.

5. NIC Science Program Activities

The primary activities identified in Figure 3 which need to be addressed as part of the science plan are as follows:

- Generation of an automated and global strategic ice product. This must be automated to allow concentration of manual effort in the derivation of tactical, daily ice charts. A data assimilation methodology appears most promising for this product and offers the opportunity for close collaboration between the scientific and operational communities.

- Development of an operational, tactical data fusion procedure to optimize the efficiency with which different data sources are utilized in generating a tactical (regional) product. This directs effort towards the analysis of data rather than in basic image manipulation. This is distinct from the strategic data assimilation procedure.

- Implementation of an operational ice tracking algorithm, as input to forecasting models, data fusion and tactical products (ice resistance parameter).

- Operational cloud masking and ice algorithm, using MODIS data. This is important not only for assisting analysts in the interpretation of visible and infra-red data, but also in allowing development of visible and infra-red algorithms which require a cloud mask in order to be effective. A cloud mask would also help in obtaining ice surface temperature information of value to the global ice product.

- SAR-based algorithms which can partially automate the generation of a tactical ice product. These are already underway and include a dynamic thresholding-based multi-year ice algorithm (University of Colorado) and a knowledge-based ice classification algorithm (University of Kansas). A ice / no ice classifier developed by Noetix also falls into this category. SAR algorithms could include a dual-polarisation ice algorithm for Envisat.

5.1 Global, Strategic Product

In order to achieve the vision of a daily, tactical ice product, it is necessary to be able to disseminate a strategic product that is generated in an automated fashion. A manually-based global product is not viable. The resolution of this global product would be on the order of 10-25 km. The importance of the global, strategic product cannot be over-emphasized. If a high quality product were available, it would result in high quality digital climatology data sets in years to come and would form the basis for critical scientific studies investigating the large-scale response of the polar regions to climate. Such a product would also be useful for planning of Arctic and Antarctic operations and logistics.

The current Navy SSM/I-derived product, from FNMOC, is unsuitable as a stand-alone strategic product. It is generated using the CAL/VAL algorithm, which is known to have significant deficiencies, including a tendency to over-estimate ice concentrations in areas of pack-ice (over large regions truncating ice concentrations to a uniform 100%). In addition, in studies which have compared SSM/I-derived ice concentrations against other sources of data (such as AVHRR), the CAL/VAL algorithm has tended to perform less well than other algorithms such as the NASA team algorithm. Until this product is improved, resources will not be able to be re-directed towards a daily, tactical product.

A plan of activities has therefore been instigated as follows, as a pre-cursor to the implementation of an operational, strategic and global ice product.

- Justify, and recommend, the immediate implementation of the NASA team algorithm at FNMOC. This will provide a rapid improvement in the SSM/I ice product quality, based on published literature and NIC ice analyst experience.

- Coordinate, and undertake, a phased development of a data assimilation scheme which starts from the existing operational set-up at FNMOC and step-by-step introduces additional data and model elements resulting in the eventual implementation of a full data assimilation scheme at FNMOC which provides products for operational interests (via NIC) and scientists (via NSIDC). Additional data sources to be considered within this implementation include Quikscat and MODIS, but also include sparse data sets such as buoy data, and ice motion vectors from 85 GHz SSM/I. In parallel, model developments will need to take place to make the model compatible with the available data.

- The data assimilation project will begin with an investigation of how the global ice product can be improved by incorporating other data sources (listed above), particularly surface temperature data from MODIS, and also in determining whether the existing FNMOC model (PIPS 2.0) can be improved by ingestion of 85 GHz SSM/I motion vectors. Evaluation exercises will be undertaken to ensure that changes recommended to the FNMOC product are fully justified. An example is the use of RGPS Lagrangian data (which can be used to precisely determine new lead openings at 3 day temporal resolution) to compare against ice concentrations from the global ice product.

- This project is planned as a joint scientific - operational venture, as the global ice product can meet the requirements of both communities. A yearly review is planned to ensure that the requirements of both the scientific and operational communities are met in this joint venture.

- Justify and recommend upgrades of the FNMOC ice product as appropriate, based on the phased data assimilation scheme.

5.2   Regional, Tactical ice product

5.2.1   Operational Ice Tracker

An operational ice tracker serves a number of purposes, including providing information on ice pressure (via convergence), assisting in data fusion / assimilation and in providing input to an ice forecast model (such as PIPS 2.0). The multiple uses of this algorithm makes it of key interest to the NIC. The requirements of the algorithm are quite demanding, however. It must be:

- robust - it must not be sensitive to image noise, slight changes in feature contrast or rotation;

- self-evaluating - it must be possible for the algorithm to be able to output a measure of the value of the product and so be reliable at picking out false vectors;

- high spatial resolution - the applications of the tracker demand that ice motion vectors are provided at high spatial resolution.

The NOW Experiment (see Appendix B) will be used to provide an initial evaluation of ice trackers, including the LARA, Noetix and RGPS/GPS algorithms, as the site presents a relatively demanding environment for ice tracking. However, it is also important to evaluate the algorithms in areas of heavy pack ice where feature-based tracking methods are likely to work less well than correlation-based methods. The RGPS will be evaluated routinely over the region covered by the ASF station mask and these results will be of interest. In addition, SSM/I 85GHz ice motion is of potential value, although the resolution may be on the low side for a tactical forecast product. Once the evaluations are completed, a plan will be established for further development or implementation of an ice tracker at NIC, or perhaps FNMOC.

5.2.2 Regional Data Fusion Tools

Data fusion is a requirement on the regional scale as well as the global scale. At the regional scale, it is expected that analysts will be required to manually generate ice charts for the foreseeable future, but data fusion could also be used to form an effective pre-processing base for the development of multi-sensor classification tools. Development of tactical data fusion techniques is a key aim of the NIC, for the following reasons:

- Reduction in time spent by analysts in switching between, and independently manipulating, data sources. Data should be available in a common processing and display environment, assimilated in such a way as to allow analysis to focus on interpretation rather than on basic image functions. Data fusion may also include some automated analysis functions which assist manual interpretation.

- Use of multiple data sources in reducing data ambiguity. All single sensor data currently used by NIC have ambiguities. Some of these can be removed, in principle, by combining information from different sensors. It is unlikely that all ambiguities will be removed, so it is not anticipated that data fusion will completely replace manual interpretation.

- Rapid evaluation of algorithms. A data fusion environment supports very quick assessment of algorithms as multiple sensor data can be compared with prototype products in a simple manner.

- More efficient data storage / display. Data fusion may allow the removal of redundant (multi-sensor, correlated) information content.

Data fusion is applicable to the generation of tactical ice products where there are a range of data sources available for processing at the spatial resolution required. At present these data sources include the DMSP OLS, NOAA AVHRR, RADARSAT and SSM/I. These sensors may be augmented by MODIS and possibly ENVISAT. The requirements for a data fusion procedure are as follows:

- High spatial resolution information should be retained during the data fusion process. Different data should not be retained only at the detail of the sensor with the lowest spatial resolution.

- The imaged surface is moving between data takes, so that co-registration of imaged objects may need to be accounted for, particularly at high resolution, using an ice tracker.

- The atmosphere will affect the visible, infra-red and passive microwave observations. The data fusion process will need to account for this explicitly where possible (e.g. through the use of a cloud filter, if available).

As these issues are very difficult to account for, it is important that the data fusion process is not inflexible and based on invalid assumptions.

Data fusion can take place at various different levels of complexity, as follows:

Low Level Data Fusion. This simply fulfills the requirements of making the analyst time more productive by minimizing time spent in undertaking basic image functions. This is therefore the minimum functionality required of data fusion. In this scenario, the ground stations / data collection and dissemination sites (ASF, etc.) construct the image data and provide these to NIC. FNMOC provide ice concentration data from SSM/I. A batch processor at NIC takes daily data, geocodes data and allocates images to appropriate region-based directories. A fusion tool would have as input the region corners (provided by a mouse drag/click mechanism or specified coordinates) and would select the resolution based on this coverage. It would then ask for a specification of sensor combinations (up to 3) which would be mapped to RED-BLUE-GREEN (RGB) or HUE-SATURATION-INTENSITY (HIS) channels, as requested. The tool would then mosaic images of single, requested sensor types which fall

within the region of interest and display accordingly. An editable version of the ice chart from the previous day could be overlaid on the multi-channel image product. In time, particular combinations of sensors and mapping functions (RGB/HIS) could be selected automatically and a batch processing function could select these combinations and write them to disk as multi-channel files.

The tool could operate as follows:

- The tool initially shows the entire region of interest by displaying the SSM/I derived ice concentration for the current day with an overlay of the ice chart from the previous day.

- The analyst can carry out a modification of the ice chart at this regional scale, or can zoom into a small area. Fusion would therefore at a variety of scales, although it would become progressively less useful at the high end of the spatial resolution where all but one sensor may be very over-sampled.

- The analyst can then switch between data (OLS, SAR, AVHRR. etc.) at a resolution appropriate for the coverage displayed, or display a multi-channel fusion product. In some cases (e.g. SSM/I ice concentrations), the data may be over-sampled. In other cases, the data will be smoothed (e.g. SAR).

- The in situ observations can be superimposed.

- The image display tool would also support editing of the ice chart from the previous day. This would include movement of lines, movement of egg symbols and editing of egg contents. This would ensure continuity between consecutive ice charts and minimize time spent in creating new regions. The line style could be adjusted automatically according to the data source being displayed in raster underneath the ice chart.

High level Data Fusion. In this scheme, data fusion serves the purpose of making intelligent use of the data rather than just taking away the routine assimilation of data from the analyst. In addition to the above functionality, data fusion can include a range of tasks which undertake interpretation on behalf of the analyst. This includes the following:

- **cloud masking**, using MODIS data, or prior to that using another cloud filter. The high spectral resolution afforded by MODIS should provide some effective cloud-masking capability. This mask can then be applied as a filter to other visible / infra-red data where the time difference is sufficiently small (data would be collected within a period of perhaps 3 hours in the case of visible / infra-red data - cloud movement would preclude all data being sufficiently close in time to allow effective cloud masking). Cloud masking could therefore be optional on data, but the default could be masking of data within a threshold time interval from the MODIS observation.

- **surface co-registration**. If an operational ice tracker was available, then this could be used to interpolate floes to their positions at a common time (for instance, 12:00 GMT). The advantage would be much improved interpretation, particularly at high spatial resolution (as floes would overlap) and much improved precision in providing the ice chart with an associated time. This could happen only if the tracker was robust, with sufficient spatial resolution, and if the area under scrutiny was not so dynamic that linear interpolation of floe position was unreasonable. This could be an optional facility.

- **generation and display of derived products**. This is potentially a very powerful benefit of data fusion. The co-registration of data at common resolution makes it relatively simple to generate and display higher level products including principal components (with equations derived from off-line analysis, representing linear combinations of different sensor calibrated pixel values providing

orthogonal information products, taking into account incidence angle), ice convergence map (derived from ice motion vectors), newly formed leads (from ice divergence), etc. These derived products can include prototype classification products based either on single sensors, or on multiple sensors. Examples include two systems currently being developed for NIC under contract - a system for classification of multi-year ice using dynamic thresholding (Fetterer, University of Colorado) and products based on knowledge-based classification of SAR sea ice data (Tsatsoulis, University of Kansas).

- **facility for archiving** of data fusion products. The archive could potentially consist of cloud mask and ice motion fields, as well as basic image data. This would provide an excellent data set for scientific and operational researchers to develop multiple-sensor algorithms and to acquire, in an easy manner, detailed datasets of regions and periods of interest.

5.2.3 Development of SAR-based Algorithms

Radar data will form the focus of the tactical ice products from NIC. The development of radar algorithms is currently being undertaken through a wide range of groups and through NIC contract work, the latter focusing on use of knowledge to classify Radarsat data, and dynamic thresholding to extract multi-year ice concentration. The Radarsat Geophysical Processor Tool (RGPS) is also of interest, with which NIC is presently associated through membership of the RGPS Science Working Group. This system promises to generate ice deformation and new ice thickness histograms, among other products. Future interests will include the use of dual polarization radar data in anticipation of Envisat data (here, ERS-2 VV and Radarsat HH data could be used to simulate this). NIC will play a role, largely through NOW, in helping to assess some of these algorithms.

5.2.4 Operational use of digital climatology data

Digital climatology data will be available from the Environmental Working Group initiative, which has grown out of the Gore-Chernomyrdin Commission. The Russian - US Arctic Atlases, for example, are derived from 1.3 million temperature and salinity data points, of which 70% were previously classified. Further valuable information is contained within the digital ice chart information from the USA, which will be available at a spatial resolution of 10 km and with a time interval of 7 days. The US charts will extend back to 1972. The digital climatology data have been extensively quality checked and edited by NIC.

As well as being of value to the scientific community, the NIC also plans to make use of the digital climatology in verifying the daily, tactical and global ice analysis charts. Initially, the verification could be manual and simply a matter of overlaying the candidate ice chart on top of a raster representation of the digital climatology. However, in the longer term the verification process could be automated such that an algorithm compares the ice chart against a digital climatology and determines the probability that the classification is correct based on past conditions for the particular time of year and region of interest. The result of the automated comparison could be a map showing color-coded areas of probability that the ice chart is consistent with expected conditions. This would allow the analyst to re-check only those areas which are suspect based on expected conditions and to see at a glance (based on color) that the ice chart is consistent. This will not act as a fool-proof way of verifying the interpretation of data, and it is not a validation in any sense, but it will serve to minimize or eradicate gross errors in ice coverage.

5.2.5 Computer-learning of ice analyst skills

Data fusion provides an excellent environment for implementing a computer-learning procedure which would be transparent to the analysts, but which may, once trained, assist in production of the daily, tactical ice chart. At the end of every session in which the analyst has completed and verified the daily ice chart, a computer-learning procedure (such as a neural network) could be used to compare the ice chart with the input data (from the various sensors) and so "learn" the attributes of the data (intensities, texture measures, perhaps shape) which determine the classification. The analyst, through generating a vector-based ice chart, will be providing the neural network with the information it requires to learn a classification. If successful, a neural network procedure could replace the previous day's ice chart as the starting point for the analysis. If, as is more likely, the procedure is successful under limited conditions (such as winter pack-ice), then the computer-learning scheme could be provided as an optional starting point for the analysis, along-side the ice chart from the previous day. Even if the scheme were to be successful only under winter conditions in areas of pack-ice, it may reduce considerably the required level of manual classification effort. Such a scheme would be unlikely to be successful in marginal ice regions as difficulties in co-registration of ice floes and changing wind speeds associated with different data would make the multi-sensor signatures associated with water and ice types inherently difficult to predict. In areas of pack-ice, co-registration of the surface may be much more precise and open water signatures (being very limited in areal extent) may be less variable, so the technique may be more successful.

5.2.6 Sea ice model upgrade

Sea ice model development is important to NIC for the purpose of optimizing the quality of its tactical forecast products. Navy sea ice models such as PIPS 2.0 are developed and run operationally at facilities with access to Class VII super-computers (e.g. Naval Oceanographic Office in Stennis Space Center, MS, and the Fleet Numerical Oceanography Center in Monterey, CA). PIPS 2.0 combines a Hibler-derived thermodynamic ice model with the Cox ocean model and applies this to the Arctic Ocean.

With the planned replacement of weekly, regionally-based but global ice chart products by daily, regionally-based and non-global ice chart products, the requirement for sea-ice models will change from large-coverage to regional coverage with more frequent update, and forecast intervals of 24, 48, 72, 96 and 120 hours. In addition, the planned development of an operational ice tracker will allow initialization of the model with ice motion vectors as well as improved SSM/I-derived ice concentrations. Models should be based on the areas of tactical interest and periods shown in Table 1. An Antarctic model for the Ross Sea region in summer would be useful, for example.

Another aspect of this work has already been mentioned - that of using the model is used in assisting with the nowcast and data play a more important role in constraining the forecast. This is a true data assimilation approach.

5.2.7 Development of multi-sensor algorithms

The logical next step from the development of data fusion data sets is to develop multi-sensor classification schemes. Currently, the lack of a routine data fusion environment makes this difficult. The extension of the University of Kansas knowledge-based work to include non-radar sensor data is a step in this direction. Once data fusion tools are in place, it may be possible to pursue other multi-sensor classification approaches.

5.2.8 Evaluation of the operational cloud-masking and ice algorithm for MODIS

A cloud-masking algorithm would be an invaluable tool for the NIC, which is a possibility based on the high spectral resolution of MODIS data. It would serve to mask cloud in optical and infra-red data, as long as the time interval was sufficiently small.

Appendix A: Glossary

AMSR	Advanced Microwave Scanning Radiometer
ASF	Alaska SAR Facility
ASL	Arctic Submarine Laboratory
AVHRR	Advanced, Very High Resolution Radiometer
AVS	Application Visualization System
CCRS	Canadian Centre for Remote Sensing
CIS	Canadian Ice Service
DAAC	Data Active Archive Center
DERA	Defence Evaluation and Research Agency (UK)
DMI	Danish Meteorological Institute
ERS	ESA Earth Resources Satellite
ESA	European Space Agency
ESIP	Environmental Science Information Partner
FNMOC	Fleet Numerical Modeling and Oceanography Center
IIP	International Ice Patrol
JPL	Jet Propulsion Laboratory
KU	University of Kansas
NASA	National Aeronautics and Space Administration
NCEP	National Center for Environmental Prediction
NDRE	Norwegian Defense Research Agency
NERSC	Nansen Environmental Remote Sensing Centre, Norway
NESDIS	National Environmental Satellite, Data and Information Service
NIC	National Ice Center
NOAA	National Ocean and Atmospheric Agency
NOW	North Open Water (north Baffin Bay)
NPGS	Naval Postgraduate School, Monterey
NRL	Naval Research Laboratory
NSCAT	Japanese ADEOS satellite wind scatterometer
NSIDC	National Snow and Ice Data Center
NSIPS	Navy Satellite Image Processing System
NWS	National Weather Service
OOAR	Office of Oceanic and Atmospheric Research
OLS	Operational Linescan System
ONR	Office of Naval Research
ORA	Office of Research Applications
PIPS	Polar Ice Prediction System
RGPS	RADARSAT Geophysical Processor System
SHEBA	Surface Heat and Energy Balance of the Arctic (campaign)
SSC	Stennis Space Center
SSM/I	Special Sensor Microwave Imager
USCG	United States Coast Guard
UW	University of Washington

Appendix B: The NOW Experiment

NIC has a berth available for a post-doctoral researcher as part of the NOW experiment. The NOW experiment is based around the North Open Water polynya, and has the aim of understanding the general role of polynyas in terms of Arctic biology and energy fluxes. Partial sponsorship is provided by the NOAA through the National Ice Center. To support this investigation a host of measurements will be taken from the region of the polynya from March to June 1998. Measurements include the following:

1. An ice camp based out of Alexandra Fjord (a distance of 10 km from the polynya), which will operate from the first week in March until May 1998. Two meteorological towers (10 meters) with a full compliment of meteorological sensors will be established on the north end of the polynya and along the west side.

2. An aerial survey is being considered with a PCSP twin otter and with the US Coast guard. Commitments have yet to be received, but it is likely that some aerial support will be provided. The US Coast guard are being approached by the NIC.

3. A ship-based activity. Measurements will include on-ship meteorological variables, rawinsonde observations, ship-based passive and active microwave data; spectral albedo (.4 to 1.1) and TIR (10.0 to 12.0 µm) for surface temperature. OLS may also be provided by NIC. Station stops will include physical property measurement of ice microstructure and in situ radiation (short and long-wave).

A detailed program of background research will be carried out to support the campaign and scientific objectives. The following "off-line" activities are envisaged:

1. Analysis of the historical context of the polynya from 1978 to 1997 using SMMR and SSM/I data. Coupled analysis will be carried out between synoptic scale meteorology / ice type and concentration and spatial and temporal patterns of creation and maintenance of the polynya.

2. A satellite remote sensing program will be implemented, involving AVHRR data; RADARSAT; ERS-2; SSM/I; Seawifs and Octs as the primary sensors of interest. RADARSAT will be provided to the bridge of the ship (data use restrictions will apply) and to the post field program analysis; AVHRR will be provided from Resolute and perhaps Boulder; ERS-will be provided from NASA.

The research program will be carried out by various institutes including the University of Manitoba, AES Canada, CCRS, University of Florida and others. Dr. David Barber of the University of Manitoba is leading the oceans and ice component of the NOW program. Logistical and research support is being provided by the NIC and the CIS, who plan to coordinate their activities to meet their common aims. A planning is meeting is scheduled for 21-22 August 1997 in Winnipeg. NIC science and logistical support is anticipated, with logistical support including, potentially, NIC - US Coast Guard equipment (rawinsonde, buoy, etc.), meteorological observer and air support.

The region of the polynya tends to be characterized by a wide variety of ice conditions which make it ideal for assessing remote sensing data sets too, and hence the interest of the ice centers extends beyond the provision of logistical support. The NIC and Canadian Ice Service (CIS) have considerable interest in using NOW to evaluate their data sources and their current and experimental information products and to this end both ice centers are investing in the project (NOAA funding to the value of $30,000 is being used invested by NIC). Specifically, the NIC will benefit from the NOW experiment for the following reasons:

- There exist a wide variety of ice conditions in a relatively small region, which makes the site excellent for evaluating and cross-comparing data and products. The experiment provides an ideal opportunity to investigate the relative detection and discrimination capabilities of these sensors;

- The program involves near real time RADARSAT and other data coverage, which enables not only an in-depth off-line evaluation of the data, but also allows evaluation of the products in near real time on the ship. Near real time evaluation is an excellent way of assessing a product, providing a learning curve that is much steeper than that provided from off-line evaluation.

- Evaluation of NIC experimental products is possible. Either these products can be generated at near real time at the NIC, or they can be evaluated off-line. The data set can also be archived for product evaluation at later dates, as additional products reach a stage of development suitable for evaluation.

- The campaign provides an excellent opportunity for close collaboration between NIC and the Canadian Ice Service, which will allow for cross-fertilization of ideas and exchange of data and product evaluation results. In particular, the program provides a framework for close contact in the development of complementary science programs.

- The program has a strong science objective which will benefit from the data resources of the ice centers. Support for this program will fulfill one of the tasks of the NIC science program, which is to assist in the broad dissemination and utilization of NIC data products.

NIC science activities are anticipated to include the following:

- Investigation of the extent to which surface features (especially new ice types, ridging, multi-year ice) can be detected and discriminated in RADARSAT data;

- Cross-comparison of NIC data and derived products to determine relative merits and deficiencies (data includes AVHRR, SSM/I, OLS; derived products include the ice TRACKER algorithm, NOETIX ice/no ice discriminator, NIC ice charts, SSM/I ice type products);

Appendix C: NIC algorithm and product requirements

As a provider of operational products, the NIC has a strong interest in a number of techniques which may be adapted for operational use from the scientific community. However, the NIC requirements are different from those of the scientific community and this appendix summarizes these requirements.

The following algorithm characteristics are of particular importance to NIC:

- applicable to the marginal ice zone;
- computationally efficient (appropriate for operational environment);
- flexible for upgrade and/or further development;
- product or technique has operational, as well as scientific, utility;
- robust;
- not automated to the detriment of wide applicability.

The following ice products are of interest to NIC:

- ice concentration;
- ice type, age and thickness;
- floe size distribution;
- lead size and orientation;
- ridge size and orientation (ice deformation properties);
- convergence / divergence;
- ice melt state (extent of rotting);
- iceberg size distribution;
- ice drift.

NIC has global interests in ice, but areas of particular interest are as follows:

- Beaufort and Chukchi Seas in summer;
- Great Lakes in winter;
- Bering Sea marginal ice zone in winter / spring;
- Ross Sea in summer;
- Barents and Kara seas in summer;
- Sea of Okhotsk in fall/winter/spring.